

EXHIBIT I

Illuminating Engineering Society

THE LIGHTING HANDBOOK
Tenth Edition | Reference and Application



David L. DiLaura
Kevin W. Houser
Richard G. Mistrick
Gary R. Steffy

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Diffuse Reflection

If a surface has irregularities that are large, not locally smooth, or is composed of minute pigment particles, it is said to be a rough surface and the reflection is diffuse. Each ray falling on an infinitesimal particle obeys the law of reflection, but as the surfaces of the particle are in different planes, they reflect the optical radiation at many angles. An idealization of this is Perfectly Diffuse Reflection, which produces a density of reflected radiation that varies with the cosine of the exitant angle, regardless of the incident angle. This idealization is often used in lighting calculations as it can radically simplify the computational work, yet provide a good representation of actual diffusely reflecting surfaces.

Total Internal Reflection

Total internal reflection of optical radiation at the interface of two transmitting media occurs when the angle of incidence, θ_1 , exceeds a certain value whose sine equals/, the ratio of indices of refraction of the two media. If the index of refraction of the first medium (n_1) is greater than that of the second medium (n_2), $\sin \theta_1$ will become unity when $\sin \theta_2$ is equal to n_2/n_1 . At angles of incidence greater than this critical angle, the incident rays are reflected totally. In most glass total reflection occurs whenever $\sin \theta_1$ is greater than 0.66, that is, for all angles of incidence greater than 41.8° (glass to air).

Spectral Reflectance

Spectral reflectance defines the reflectance for optical radiation of a material at a series of narrow wavelength bands. Figure 1.21 shows examples of spectral reflectance data.

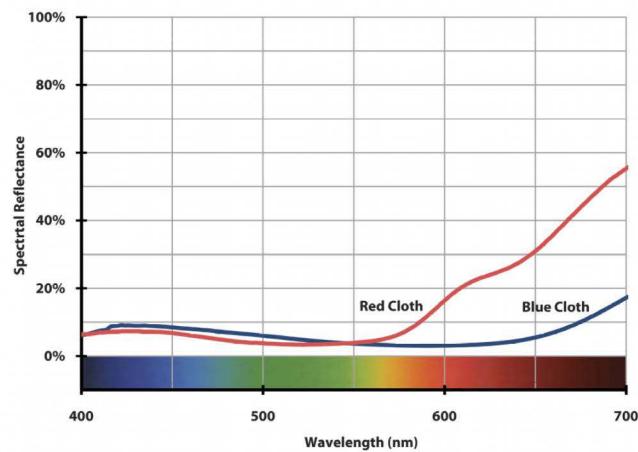
1.5.1.2 Transmission

Transmission is the process by which a part of the optical radiation falling on a material passes through it and emerges from it. Transmission is affected by surface reflections and absorption within the material. The geometry of the exitant radiation is used to describe transmission as: image preserving, diffuse, and spread. The dependency on incident wavelength is described as spectral transmittance. The absorption of optical radiation within a material can be described by the Beer-Lambert Law of Absorption. Transmission through practical materials involves reflections at the exterior and interior of its interfaces as well as absorption within the material itself. This is shown in Figure 1.22. Summing the infinite number of transmission paths gives the total transmission:

$$\tau(1 - \rho)^2(1 + \rho^2\tau^2 + \rho^4\tau^4 + \rho^6\tau^6 + \rho^8\tau^8 + \dots) = \frac{\tau(1 - \rho)^2}{(1 - \rho^2\tau^2)} \quad (1.10)$$

Figure 1.21 | Spectral Reflectance

Spectral reflectance of red and blue cloth.



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Framework | Physics and Optics of Radiant Power

Image Preserving Transmission

If transmissive material does little or no scattering and if the incident and exitant planes of the material are parallel, then rays are offset, but have the same direction. In this case the material is said to be "transparent". That is, an image of an object viewed through such a material is essentially undisturbed. Figure 1.23 shows this type of transmission.

Spread Transmission

Spread transmission materials combine varying surface geometry and varying absorption to scatter and refract incident radiation into a relatively wide exitant cone. This is usually produced by surface roughness. Table 1.3 shows typical ranges of transmittance for materials used in luminaires and buildings.



Diffuse Transmission

Diffusing materials scatter optical radiation more or less in all forward directions.

Perfectly diffuse transmission is an idealization in which the transmitted radiation has a density that varies with the cosine of the exitant angle, regardless of the incident angle. This idealized material is often used in lighting calculations as it can radically simplify the computational work yet provide a good representation of diffusely transmitting surfaces.

Spectral Transmittance

Spectral transmittance defines the transmittance for optical radiation of a material at a series of narrow wavelength bands. Figure 1.23 shows examples of spectral transmittance data for three types of fenestration glass [22].

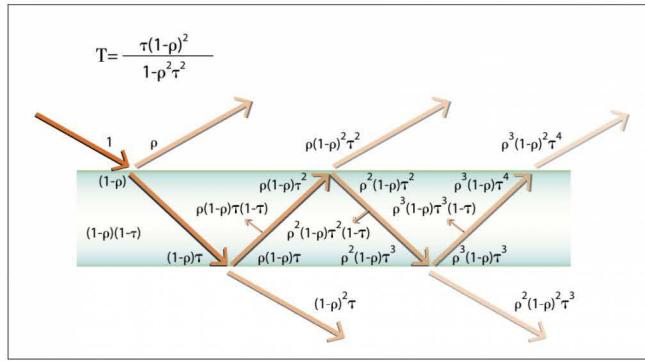


Figure 1.22 | Components of Transmittance

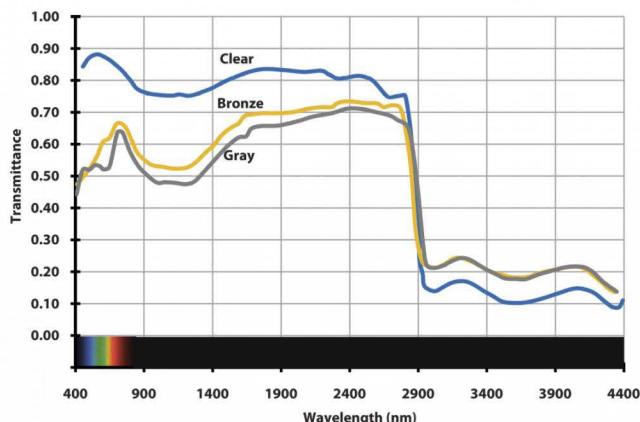
Transmittance through a slab of material involving absorption and reflection. T is the total transmittance, ρ is the reflectance at an interface, τ is the transmittance within the material along the path of travel. Total transmittance involves multiple paths through the material.

Table 1.3 | Transmittances for Some Common Materials

Material	Form or Treatment	Transmittance
Glass	Clear and optical coated	0.80-0.99
	Configured, etched, ground, or sandblasted	0.75-0.85
	Opalescent and alabaster	0.55-0.80
	Flashed opal	0.30-0.5
	Solid opal	0.15-0.40
Plastic	Clear prismatic lens	0.70-0.95
	White structural glass	0.30-0.70
	Colored	0.05-0.30
	Marble	0.05-0.30
	Alabaster	0.20-0.50

Figure 1.23 | Spectral Transmittance

Spectral transmittance from the visible to the far infrared of three types of glass used in building fenestration systems.



Willebrord Snell, early in the 17th century, found the simple relationship between the sines of the incident and refracted angles, and the refracting material's index of refraction. Snell never published his results but **René Descartes** found the same relationship (or saw Snell's manuscript and plagiarized it) and published it in 1637 in his famous work on optics. One measure of the success of the wave theory proposed by Augustine Fresnel was its ability to predict the amount of refraction.

1.5.1.3 Refraction

A change in the velocity of optical radiation occurs when it leaves one material and enters another of different optical density. The speed will be reduced if the medium entered is denser, and increased if less. Except at normal incidence, the change in speed always is accompanied by a bending of the optical radiation from its original path at the point of entrance. This is known as refraction. The degree of bending depends on the relative densities of the two substances, on the wavelength of the optical radiation, and on the angle of incidence, being greater for large differences in density than for small. The optical radiation is bent toward the normal to the surface when it enters a denser medium, and away from the normal when it enters a less dense material. The change in direction is governed by *Snell's Law*:

$$\sin(\theta_1)n_1 = \sin(\theta_2)n_2 \quad (1.11)$$

Where:

n_1 = index of refraction of first medium

n_2 = index of refraction of second medium

θ_1 = incident angle rays make with the plane separating the media

θ_2 = refracted angle rays make with the plane separating the media

Figure 1.24 shows refraction at the two air-glass interfaces. Materials exhibit an index of refraction that changes with wavelength, so the refracted angle depends on wavelength.

1.5.1.4 Interference

When two optical radiation waves of the same wavelength come together at different phases of their vibration, they can combine to make a single wave. If the phases are opposite the waves subtract and the resulting amplitude is the difference of the two amplitudes, possibly zero. If the phases are the same the waves add and the resulting amplitude is the sum of the two amplitudes. Figure 1.25 shows the resulting interference when optical radiation refracts and reflects from thin films. Part of the incident optical radiation ab is first reflected as bc. Part is refracted as bd, which again reflects as de, and finally emerges as ef. If waves bc and ef have wavefronts of appreciable width, they will overlap and interfere.

1.5.1.5 Diffraction

Due to its wave nature, optical radiation will be redirected as it passes by an opaque edge or through a small slit. The wavefront broadens as it passes by an obstruction, producing

Table 12.1b | Spatial Factors: Part Two

Factor	Design Media	Traits of Interest	Criteria	Techniques to Consider ^a
Spatial Definition	Planes	• Luminances » Uniformities » Patterns	• Enhance planes • Accent planar textures	① • Use frontal wallwash across plane or planes of choice • Use grazing wallwash on plane or planes of choice
	Planar Intersections	• Ceiling-to-ceiling • Ceiling-to-wall • Wall-to-wall • Wall-to-floor	• Articulate edges • Articulate juxtapositions • Articulate design style	① • Accent plane changes of choice ② ⑤ • Accent plane intersections • Use lighting effects or luminaires to complement style
	Design Features	• 2-D Surface • 3-D Object	• Focus attention	⑥ ⑦ • Accent single large feature • Accent multiple features for "massing" effect
Circulation	Wayfinding Markers	• Luminances » Patterns » Magnitudes • Color » Patterns » Magnitudes	• Define path • Define destination	• Accent elements such as pilasters or niches ⑧ • Accent point or area of destination • Accent colorful features such as artwork ⑨ • Accent or saturate color feature at destination

a. Numbered notes are keyed to Figures 12.7-12.10.

12.3 Psychological Factors

Attraction and subjective impressions are categorized as psychological factors and are premised on lighting influencing visual attraction and people's impressions or reactions to a setting [2] [3] [4] [5]. What follows should be considered indicative, since much is based on anecdotal trends, limited research, or some influence of fundamentals or rules in the FRAMEWORK FOR LIGHTING Section. Some guidance is little more than talking points for thought and discussion with the design team to advance a lighting design.

12.3.1 Attraction

Reflected approach means taking advantage of the surface's or object's reflective qualities and using front lighting techniques. Lighter-toned finishes reflect a lot of light and can be frontal lighted with relatively low-wattage accent or wallwash lights. Darker-toned finishes reflect little light, requiring relatively high-wattage accent or wallwash luminaires.

Transmitted approach means taking advantage of the surface's or object's transmissive qualities and using back lighting techniques. High-transmission materials such as clear, frosted, or pale-colored glass and acrylics transmit a lot of light and can be backlit with relatively low-wattage luminaires. Cloudy, deeply-saturated-colored, or mostly opaque glass and acrylics transmit little light, requiring relatively high-wattage luminaires.

Reflected and transmitted approaches are most powerful when material color is matched with color of light. Colored light on neutral reflecting or transmitting surfaces exhibit more subtle results. The means of generating the colored light itself greatly affects the outcome. Many colored LEDs emit in very narrow bands of wavelength and therefore appear highly saturated. If these are combined with reflective or transmissive surfaces that are highly saturated and spectrally similar, the color effect is strongest. If spectral reflectance, transmittance, and radiation data were available for the respective surfaces and lamps, matching and energy optimization would be easy. Where neutral reflecting or transmitting surfaces are used, colored LEDs or other lamps exhibiting good color saturation (for example, colored fluorescent and cold cathode or neon lamps) will generally offer satisfactory results. Mockups are better and more certain than data matching or renderings based on data, however complete.

Figure 12.2 illustrates color effect of white-light from 3000 K and 80 CRI CMH lamps on saturated-color glass. Figure 12.9 illustrates color effect of white-light from 3000 K and 80 CRI CMH lamps and general background lighting beyond from 3000 K and 85 CRI T8 lamps on saturated-color glass similar to that in Figure 12.2. Figure 12.11a illus-

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Design | Components of Lighting Design



Figure 12.7 | Planar Intersections

Numbered notes are keyed to Table 12.1b. Light reinforces the elegant modernity of sweeping architectural forms and the selective use of bold color. Where ceiling planes step up or down from one another, light coves differentiate these planar intersections 1. The curvilinear and angular colored forms are visually strengthened with light slots at the juncture of the ceiling and the wall of the forms 2. These lighted colored forms assist in assessing space depth and activity and help visually pull users into the space 3. In the context of the seating area, uniform wall lighting establishes a comfortable backdrop against which observing and conversing amongst people is facilitated 4. This uniform wall lighting also augments downlighting and cove lighting in the area for localized high quality facial modeling—an important aspect of conversing.

» Image ©Elliott Kaufman/Beateworks/Corbis



Figure 12.8 | Planar Intersections

Numbered notes are keyed to Table 12.1b. Light emphasizes the angular undulations of walls 5 and readily defines the extent and configuration of space for users—particularly helpful for first-time users of hotels for example. Such a configuration of light works to “energize” the space. In this figure and in Figure 12.7, light patterns reflected in the polished floors add visual interest or visual noise, depending on one’s design perspective and the intended audience. These patterns can be disorienting for visually impaired and older occupants and may have the unintended consequence of slowing circulation movement. With polished floors, any lighting in or on walls and in or on ceilings will create reflected patterns of light.

» Image ©Fernando Alda/Corbis



Figure 12.9 | Features and Planes

Numbered notes are keyed to Table 12.1b. The translucent feature wall exhibits significant depth when backlit (white light backlighting fused, cast, multi-colored glass). The feature wall is completely lighted to serve as backdrop for the corporate logo 6 which is front-accented and as the “welcome” focal point of the lobby 7.

» Image ©Beth Singer Photographer, Inc.



Figure 12.10 | Wayfinding

Numbered notes are keyed to Table 12.1b. The repetitive use of triple-light arrays in the six vertical architectural elements 8 identify this reception area. Although luminance of each triple-light is relatively sedate—this a reception to a spa where bright, harsh lighting would be inappropriate—their repetition identifies the significance of the destination.

» Image ©Atlantide Phototravel/Corbis

trates color effect of blue fluorescent lamps on various surfaces. Figure 12.11b illustrates color effect of good-color-saturation colored fluorescent lamps (red-sleeved-at-factory) backlighting a saturated-color acrylic transmissive surface.

For purposes of attraction, *luminance ratios* of at least 3-to-1 (object-to-background) are necessary for one object to exhibit some degree of prominence from its background. Where a distinct focal cue is desired, a luminance ratio of at least 10-to-1 is appropriate. For dominating focal points, a luminance ratio approaching 100-to-1 is needed. Figure 12.11a illustrates the visual effect of a focal object (the white glass bead panels) to background (the dark wood wall surround) where the luminance ratio reaches 70-to-1 at night.

Hierarchies of viewing can be established by considering the effect of various luminances or colors throughout a space. Figure 12.11a illustrates luminance hierarchies to compose a setting.

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Luminance ratio is the ratio of the luminance of one object or surface to that of its background or to another object or surface. Greater ratios result in more distinct visual difference.

The Lighting Handbook | **12.7**

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Figure 12.11a | Color and Luminance Attraction

Color and luminance are used for visual attraction of the registration area in a hotel lobby, visible from a porte cochere off to the right. Static colored light in recessed ceiling slots and dynamic luminous panels set the scene in blue at dusk and through morning. Glass bead panels behind the front desk are strongly lighted for significant luminance. Layering luminances from the table luminaires at the front desk and along the leading edge of the front desk stone top help define and accentuate the 3-dimensional character of the lobby registration area. See an outline of techniques in Table 12.1b | Spatial Factors: Part Two.

» Image ©Kevin Beswick, www.ppt-photographics.com



Figure 12.11b | Color Attraction

Color and luminance are used for visual attraction of the distant reading area from within the context of library stacks. Red translucent acrylic panels are backlit with red-filtered fluorescent lamps for deeply saturated color.

» Image ©Balthazar Korab Photography Ltd.



12.3.2 Subjective Impressions

The design of lighting should not be limited to utility, task, and physiological needs. Indeed, a truly functional lighting design addresses qualitative factors affecting users' attitudes, preferences, well-being, and motivation. [6] [7] How people feel about a space and react to a setting, in part, appear related to so-called cue-patterns.

Cue patterns are categorized by three lighting modes: location (with central or perimeter cue patterns), uniformity (with uniform or nonuniform cue patterns), and relative strength (with bright or dim cue patterns). Cue patterns are relative terms and are not quantified. These may be generated by electric light or daylight. Perimeter means patterns of light are in the user's periphery, commonly at the perimeter of a space, but could be off to the side of a sitting area or work area. Central means the patterns of light are related to the central room area. Uniform as used here indicates that the patterns of light are consistently or regularly arranged. Nonuniform means the patterns of light are applied intermittently or irregularly, but not in a completely random or haphazard manner. Nonuniform patterns of light typically relate to surface materiality, objects, and focal points as shown in Figures 12.12 and 12.13.

Subjective impressions affected by the three lighting modes are preference, privacy, relaxation, spaciousness, and visual clarity. Each of these impressions is influenced by a distinct combination of lighting modes. For each of these subjective impressions, Table 12.2 identifies the supporting lighting modes in order of influence, design implications, techniques for consideration, and typical applications. [3] [5] [8] Any of these subjective